HYDROLOGY OF MIDDLE CANYON, OQUIRRH MOUNTAINS, TOOELE COUNTY, UTAH

by

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ABSTRACT

The purpose of this investigation was to determine the factors in the hydrologic cycle of Middle Canyon, Tooele County, Utah, and to balance the hydrologic budget of the Middle Canyon drainage basin as an aid to future development of the canyon's water supply. A reconnaissance study of the geology of the canyon was made to determine the influence of geologic factors on the hydrology of the canyon.

The Oquirrh Mountains is a typical north-south trending range of the Basin and Range province, and is believed to be a block, faulted and uplifted on its western edge and tilted to the east. Middle Canyon is cut entirely into the Pennsylvanian-Permian Oquirrh formation, which is composed of over 16,000 feet of alternating limestones and quartzose sandstones, with the sandstones predominating. Quaternary deposits in the drainage basin, which include alluvial, colluvial, and some glacial material, are thicker in the upper canyon.

The greatest concentration of faulting in Middle Canyon is in the upper canyon. These faults are high-angle normal faults with displacements in the order of 100 feet. Jointing is common in the Oquirrh formation, although definite joint systems were not apparent in the Middle Canyon area.

Middle Canyon is a structurally controlled drainage basin developed on the sharp decrease in dip where the steeply-dipping northeast limb of the Long Ridge anticline passes into the structural terrace between the anticline and the Bingham syncline. The longitudinal profile and profiles across the

main channel indicate that the lower canyon has been rejuvenated, probably as a result of movement on the mountain-front fault at the mouth of the canyon.

The discharge from Big Spring, which occurs after the spring thaw in the high parts of the drainage basin, is the main source of supply from Middle Canyon. Examination of the available 11 years of records showed that, per unit of precipitation, the total annual discharge of Middle Canyon has decreased since 1910. Although mining activities in the Oquirrh Mountains have been cited as a possible cause, similar decreases in discharge from many drainage basins in Utah indicate that most of the decrease in discharge from Middle Canyon is due to a change in climate.

In Middle Canyon, the geology may have strong local effects on the hydrology. Leakage could be occurring through fault and fracture zones, joints, or solution channels in limestone beds. The Quaternary deposits of the drainage basin serve as the main storage material for ground water, and alluvial deposits in the main channel transmit water from the upper canyon to the springs and drains at the canyon mouth. The thicker surficial deposits in the upper canyon make it a more important storage area than the lower canyon, and any zones of leakage in the upper canyon would likely result in greater water loss than would similar outlets farther down canyon.

The hydrologic budget for the 1947 water year was calculated by comparing estimates of gains and losses of water in the canyon. In 1947, about 50% of the water estimated to be available for stream flow and channel underflow was unaccounted for, and was assumed to represent leakage out of the drainage basin. Because fault and associated fracture zones account for most of the water encountered in the mine workings of the nearby

Bingham district, most of the leakage in Middle Canyon was assumed to be occurring in similar zones.

Chemical analyses of water samples taken at various locations in the canyon in the late summer of 1959 showed that the highly mineralized water from the Utah Metals tunnel has little effect on the water quality at the canyon mouth. This indicates that much of the tunnel water is lost by leakage in the upper canyon during the dry part of the year.

The future development of Middle Canyon water can best be planned after obtaining additional information on movement of water through the channel fill. Much of this information could be supplied by completing the drilling project that was proposed in 1954 to investigate the hydrologic characteristics of the channel fill in the north-center of section 6, T. 4 S., R. 3 W.

INTRODUCTION

Purpose and Scope of the Investigation

This investigation was suggested as a thesis project by Professor Ray E. Marsell, and was included as a part of a larger U. S. Geological Survey study of the geology and ground-water resources of Tooele Valley, Utah, made by Harry D. Goode and the writer. This part of the Tooele Valley study was conducted under a cooperative agreement between the U. S. Geological Survey and the Utah Water and Power Board.

The purpose of this investigation was to determine the various factors in the hydrologic cycle of Middle Canyon in an attempt to balance its hydrologic budget. The estimates of the hydrologic budget and the conclusions about water losses should be given strong consideration in any future attempt to develop the water resources of the canyon.

A knowledge of the geologic setting of a watershed is of prime importance in determining the relative influence of the various factors of its hydrologic budget. Therefore, a large part of the investigation consisted of a study of the geology of Middle Canyon and its influence on the hydrologic cycle. A map of the geologic structure of the canyon was prepared, showing attitude of the sedimentary rocks, known faults, and the outcrop pattern of the two thick limestone beds in the sedimentary section. Profiles of the canyon were plotted to bring out geomorphic features that might be related to the hydrologic cycle.

The remainder of the investigation was centered around the hydrologic budget of Middle Canyon. An attempt was made to quantitatively balance the water gains and losses in the canyon as an aid to future water development.

Previous Investigations

The southern half of the drainage area of Middle Canyon was included in U. S. Geological Survey Professional Paper 173, "Geology and Ore Deposits of the Stockton and Fairfield Quadrangles, Utah", by James Gilluly. At the present time, Ralph J. Roberts and Edwin W. Tooker of the U. S. Geological Survey are engaged in mapping the Oquirrh Mountains north of the area studied by Gilluly.

The writer also had access to an unpublished Soil Conservation Service report, "Interim Progress Report of Middle Canyon Water Studies", by D. F. Lawrence and G. M. England, and a report made to the Middle Canyon Water Study Committee entitled "Report on Inspection of Proposed Ground Water Studies in Middle Canyon, East of Tooele, Utah", by J. Neil Murdock, consulting geologist.

Geography

Location, extent, and relief of the drainage basin

Middle Canyon is near the center of the eastern edge of Tooele County, Utah (fig. 1), and the eastern border of its drainage basin is at the intersection of latitude 40° 30' north and longitude 112° 15' west. The drainage basin trends northwest and includes an area of 11.3 square miles, which lies in the Tooele, Bingham Canyon, and Fairfield quadrangles. The mouth of the canyon is about two miles southeast of the city of Tooele, and a gravel road goes from the mouth of the canyon to the Oquirrh Mountain divide at the head of the canyon. In 1959, the Utah National Guard extended this road to the north along the Oquirrh divide to a point on the western side of West Mountain, giving access to the northern half of the upper canyon.

The topography of Middle Canyon is steep and rugged, with elevations ranging from 5,400 feet at the mouth of the canyon to more than 10,300 feet on the southern rim of the drainage basin. In the lower half of the canyon, the main channel is narrow, and the tributaries are short and steep. The upper half of the drainage basin is more mature than the lower half, with the main channel broader and the tributary canyons larger and better developed. The upper half of the canyon has two systems, the main channel and Left Hand Fork. About half-way up Middle Canyon,

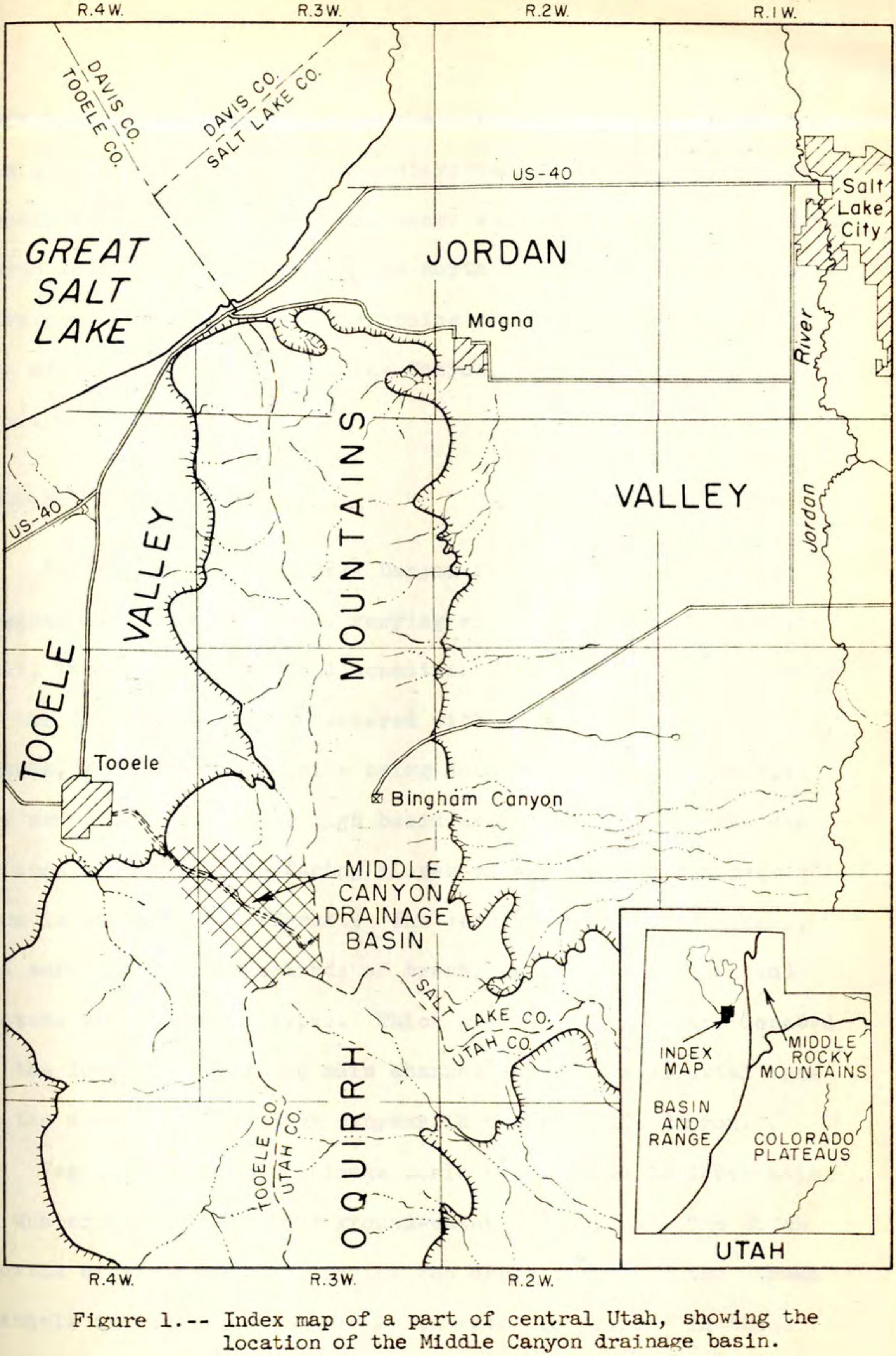

Figure 1.-- Index map of a part of central Utah, showing the location of the Middle Canyon drainage basin.

Left Hand Fork branches off to the northeast and then turns to the east. It has no large tributary canyons. The main canyon continues to the southeast and shows strikingly different characteristics on its two sides. The north side is steep with poorly developed tributary canyons reaching to the high southern rim. One of these canyons, White Pine Canyon, is becoming graded at its lower end.

Vegetation

The vegetation of Middle Canyon is typical of the upland regions of the Great Basin, varying widely in response to rainfall, temperature, and soil conditions. The north-facing slopes of the drainage basin are covered with timber, with Douglas fir, spruce, and some yellow pine being common. On White Pine Flat and several of the other high basin areas, stands of aspen can be seen. On the south-facing slopes of the canyon, the vegetation is strikingly different. The vegetation is much thinner, and scrub oak, various kinds of brush, herbaceous plants, and grasses are the chief types. Thick growths of trees are located in the lower parts of the main channel and on the alluvial fans at the mouths of tributary canyons in upper Middle Canyon.

Vegetation in the drainage basin gives valuable information on Quaternary deposits and ground-water conditions. The thick growths of trees on the alluvial fan deposits and in the stream channels indicate that underflow of water is present in these locations. The thicker growth of vegetation on the north-facing slopes of the drainage basin is the result of an adequate supply of water stored in the thick alluvial, colluvial, and soil cover on these slopes.

Climate

The climate of the Middle Canyon region is typical of the mountainous areas of the Great Basin. The Great Basin as a whole is semiarid, but the higher parts of the Oquirrh Mountains, in common with many of the Great Basin mountain ranges, receive enough precipitation to be classified as humid.

A storage precipitation gage installed in White Pine Canyon, a tributary of Middle Canyon, by the Soil Conservation Service in 1956, indicates that the station has a mean annual precipitation of over 30 inches. This is about twice the mean annual precipitation of 15.81 inches for the period 1931-1952 at the Tooele weather station. The pattern of precipitation is the same for the two stations, the difference being that each storm deposits about twice as much moisture at the Middle Canyon location. The pattern of both stations is similar to that of most stations in northern Utah, where the maximum precipitation occurs in late winter and early spring and the minimum occurs in summer.

Figure 2 shows the cumulative departure from the 1897-1952 mean annual precipitation at Tooele for the period 1897-1959. This curve shows that precipitation in the vicinity of Tooele occurs in an irregular cyclic pattern made up of alter-

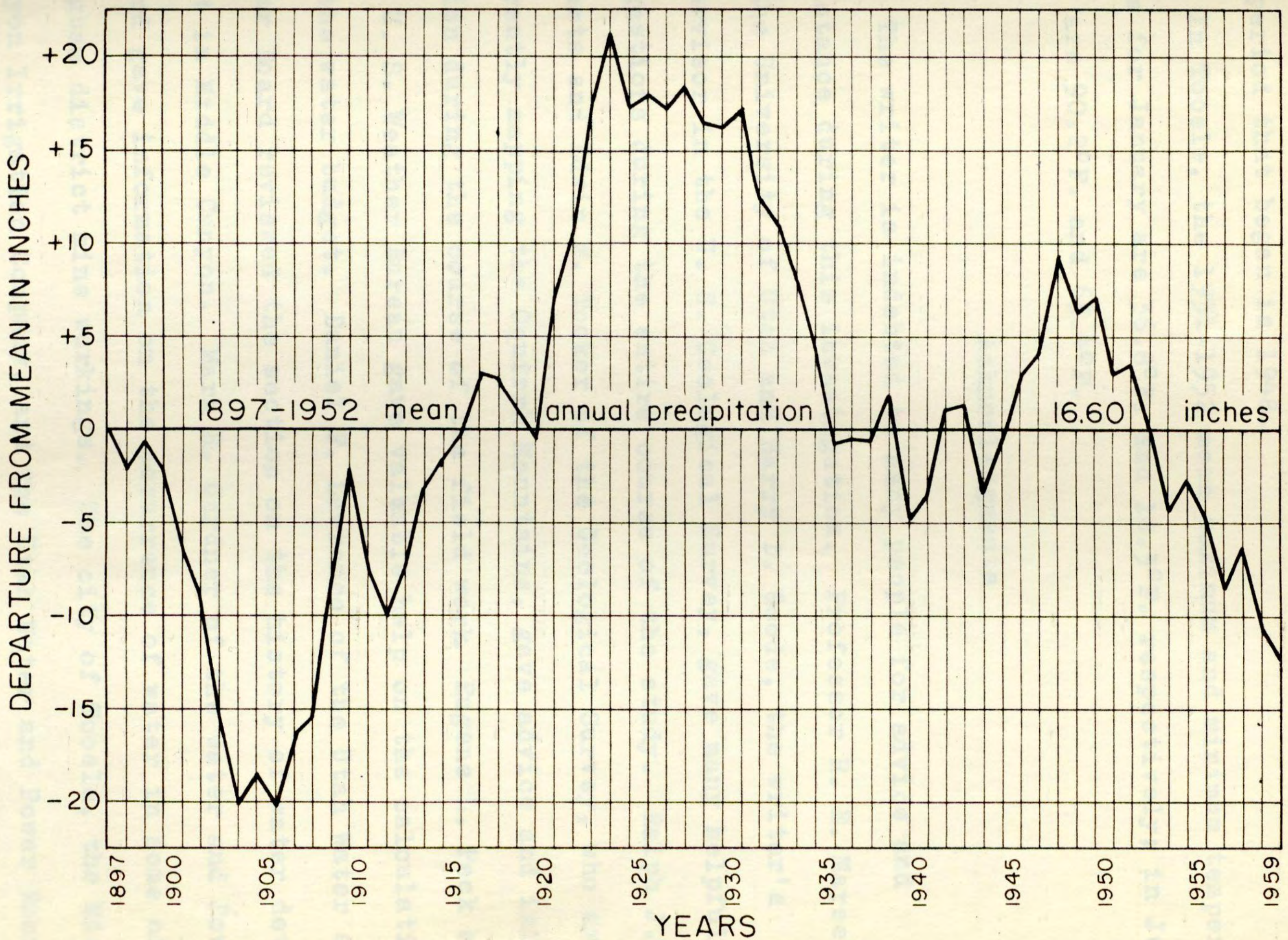

Figure 2.-- Cumulative departure from the 1897-1952 mean annual precipitation at Tooele, Utah, for the period 1897-1959.

nating sequences of wet and dry years. 1959 is included in a dry period that began in 1948.

In Tooele, the 1931-1952 mean maximum and minimum temperatures for January are 36.8°F. and 18.3°F. respectively; in July they are 90.2°F. and 63.4°F.

Acknowledgments

The writer is indebted to many people for advice and assistance during this investigation. Professor R. E. Marsell of the University of Utah and Harry D. Goode, the writer's supervisor in the U. S. Geological Survey, gave many helpful suggestions during the entire course of the study. Ralph J. Roberts and Edwin W. Tooker of the Geological Survey, who are currently mapping the Oquirrh Mountains, gave advice and information during the course of the field work. Eugene L. Peck of the U. S. Weather Bureau gave valuable help on the calculation of the water budget. Daniel F. Lawrence of the Utah Water and Power Board reviewed the section on the history of water development in Middle Canyon. Mark R. Gardner of the Water and Power Board gave information on the occurrence of water in some of the Bingham district mine workings. The city of Tooele, the Middle Canyon Irrigation Company, and the Utah Water and Power Board were generous in allowing the use of all their records pertaining to Middle Canyon. Marvin L. Millgate did most of the drafting for the thesis.

GEOLOGY

The Oquirrh Mountains is a typical north-south trending range of the Basin and Range province. The range has been described as a block, faulted and uplifted on its western edge and tilted to the east (Gilluly, 1932, p. 91). The range is composed of Paleozoic sedimentary and Tertiary igneous rocks, and the greater part of the range is made up of the Pennsylvanian-Permian Oquirrh formation, which has a thickness of over 16,000 feet. The basins bordering the Oquirrh Mountains are filled with Tertiary and Quaternary alluvial and lacustrine deposits.

The structure of the Oquirrh Mountains consists of a series of large folds trending northwest-southeast and, on the western side of the range, plunging to the northwest. These folds are probably related to the late Cretaceous-early Tertiary Laramide orogeny, and have been truncated by late Tertiary normal faulting.

Stratigraphy

The bedrock of the Middle Canyon drainage basin is the Pennsylvanian-Permian Oquirrh formation, which has been intruded in places by Tertiary igneous rocks. Unconsolidated Quaternary deposits occur along the main and tributary channels and in some of the high "basins" on the south rim of the drainage area.

No attempt was made to make a detailed stratigraphic study of the Oquirrh formation, but the local stratigraphy was studied to determine its relation to the hydrology of the canyon.

Pennsylvanian-Permian

Oquirrh Formation

The Oquirrh formation was named and defined by Gilluly in 1932. It is a great thickness of alternating limestones and quartzose sandstones, with the sandstones predominating. The formation makes up the surface outcrop over much of the range, and essentially makes up the entire volume of the northern half of the range.

The total thickness of the Oquirrh formation is not accurately known in the Oquirrh Mountains. Gilluly (pp. 34-36) gave a total thickness of 16,000 to 18,000 feet and stated that the top of the formation may not be present in the range.

The Oquirrh formation is entirely Pennsylvanian in age at the type locality (Gilluly, p.36), although Bissell (*in* Utah Geol. Soc., 1959, p. 126) stated that there may be a full Wolfcampian (lower Permian) section in the northern part of the range. Permian age of the upper part of the Oquirrh formation has been established in the Wasatch Range, about 30 miles to the east, by the work of Bissell, Baker, and Thompson (Bissell *in* Utah Geol. Soc., p. 127).

The Oquirrh formation is dominantly quartzose sandstone, cemented by either silica or calcium carbonate. The term quartzite is commonly applied to these sandstones and will thus be used in this report, although to be strictly correct this designation should be applied only to the silica-cemented sandstones. Both silica- and carbonate-cemented types have a detrital fraction composed almost entirely of quartz grains that range in size from coarse silt to fine sand, and minor amounts of heavy minerals. Bending and cross-bedding occur commonly in the quartzites.

Nygreen (1958, p. 18) made the following statement on the effects of the cementing material:

> Cementing material is of carbonate or silica, and this is usually reflected in weathering characteristics. The quartzose sandstone and quartzose siltstone are carbonate-cemented, commonly cross-bedded, and are characterized by having a light to medium-gray or light brown color on fresh surfaces and light brown weathered color. The carbonate-cemented sandstone is only moderately resistant to weathering, being less resistant than orthoquartzite and limestone. . . . The orthoquartzites are silica-cemented, usually massive and characteristically brown on both weathered and fresh surfaces. They are resistant to weathering, characteristically forming ridges.

The limestones of the Oquirrh formation are typically light gray on a weathered surface and dark blue to black on a fresh surface. They are fine grained and commonly contain discontinuous zones of chert nodules.

Gilluly tried to find beds which he could correlate from the southern Oquirrh area to Bingham Canyon, but was unsuccessful. He claimed that the quartzite beds were lenticular and would lens out in a short distance (Gilluly, p. 35). The limestones were considered to be less lenticular and could be traced for considerable distances. Roberts (oral communication,

1959) stated that not as much lensing occurs as Gilluly had previously reported.

In the Middle Canyon area, the sedimentary outcrops are all of the upper half of the Oquirrh formation. Two thick limestone beds crop out along the length of Middle Canyon with little change in thickness. Emmons (1905, p. 24) stated that "the nearly adjoining limestones, locally designated the 'Commercial' and 'Jordan' members, which are the most important ore carriers of the [Bingham mining] district [South of Bingham Canyon, shown on figure 1], have been traced in practical continuity from near the mouth of Bingham Canyon southward and westward to the Commercial and Jordan Mines and again along the southern and western slopes of West Mountain beyond the limits of the map, and down Tooele [Left Hand Fork of Middle] Canyon."

Field work shows that the two thick limestone beds in Middle Canyon are the Jordan and Commercial members of the Bingham quartzite. The Bingham quartzite was named and defined in the Bingham district by Keith (1905, p. 33). Gilluly (p.34) recognized that the Bingham quartzite was included in the upper part of the Oquirrh formation, but the Bingham quartzite has never been formally redefined. In this report, the terms lower (Jordan) and upper (Commercial) limestone will be used. A revision of the nomenclature of the Oquirrh formation will be published in the future by Roberts and Tooker (Roberts, written communication, 1960).

On the geologic map (fig. 3), these two limestones are the only beds of the Oquirrh formation that are shown in detail. The offsetting of strata caused by the numerous faults on the ridge separating the main canyon from Left Hand Fork necessitated the use of inferred contacts for the lower (Jordan) and upper (Commercial) limestone members. In this area, detailed mapping of these limestones was not considered essential to a hydrologic study of Middle Canyon.

Lower (Jordan) limestone member.--The lower (Jordan) limestone is the lower and more prominent of the two limestone beds that crop out in Middle Canyon. As is typical with other limestones in the Oquirrh formation, the lower (Jordan) limestone is a fine-grained, blue to blue-black, bedded limestone with numerous zones of chert nodules. The limestone is resistant to weathering and forms ledges on all but the most heavily covered slopes. It weathers to a light gray, and the included chert nodules are dark gray to black on the weathered surface.

The upper and lower contacts of the lower (Jordan) limestone change locally, but in general the lower contact is sharp and the upper gradational. At the upper contact with the overlying quartzite, stringers and lenses of brown-weathering calcareous quartz sandstone interfinger with the upper part of the limestone. The lower(Jordan) limestone is 300 feet thick at West Mountain at the northeast corner of the drainage basin, and averages 200 feet in the Bingham district (Keith, p. 40).

The writer measured an approximate thickness of 340 feet of this member by pacing a vertical outcrop on a spur on the southern side of lower Middle Canyon.

Above the lower (Jordan) limestone, and separating it from the upper (Commercial) limestone, is 200 to 300 feet of tan quartzite. This quartzite varies in thickness more than either of the two limestone beds.

Upper (Commercial) limestone member.--Above the tan quartzite is the upper (Commercial) limestone member, which is not exposed as prominently as the lower (Jordan) limestone because it is commonly covered with talus derived from overlying quartzites. Keith (p. 40) stated that the Commercial member is the most extensive of the limestone bodies of the region.

In lithology, the upper member is similar to the lower (Jordan) member, being a fine-grained blue to blue-black limestone, gray on the weathered surface. There are more chert nodules present, and in many places the nodules join one another to form continuous beds of chert.

The lower contact of the upper (Commercial) member is fairly sharp and resembles the lower contact of the lower (Jordan) member. The upper contact varies from place to place but in general the gradational zone between the limestone and the overlying quartzite is absent or much thinner than the zone that forms upper contact of the lower (Jordan) member.

Keith (p. 40) reported an average thickness of 200 feet for the Commercial member, and the writer measured an approximate thickness of 175 feet by pacing.

Tertiary intrusive rocks

Quartz monzonite porphyry intrusions crop out across the upper part of Middle Canyon in a zone that extends to the northeast in the direction of the Bingham district. Large outcrops of porphyry are on the Middle Canyon drainage divide above and to the west of White Pine Flat, and on the north wall of Middle Canyon proper about 2,000 feet below the mouth of White Pine Canyon. Small outcrops occur on the west wall of lower White Pine Canyon, in the drainage west of White Pine Canyon, and in the upper Left Hand Fork drainage.

Gilluly (p. 54) cited bending of a limestone at its contact with the monzonite as evidence for forcible intrusion of the monzonite bodies. He stated that the quartz monzonite represents the last stage of the local igneous activity, and assigned it an early Tertiary age.

The intrusive bodies could be controlled by the northeast trend of the faults in the upper part of Middle Canyon, and are certainly genetically related to the intrusions of the Bingham district.

Tertiary-Quaternary Salt Lake formation

Thomas (1946, p. 116-117) stated that the Salt Lake formation forms the foothill slopes above the highest shore lines of Lake Bonneville in discontinuous areas around the margin of Tooele Valley. He described this formation as a typical fanglomerate composed of poorly sorted subangular to subrounded boulders, gravel, and sand in irregular beds loosely to firmly cemented by a calcareous cement.

The Salt Lake formation is shown northwest of the mouth of Middle Canyon on the geologic map (fig. 3). In this area, poorly cemented exposures of the formation can be seen along the west side of the road to the canyon mouth.

Quaternary

Quaternary deposits in the Middle Canyon drainage basin include alluvial deposits in the stream channels, colluvial deposits, glacial deposits in the upper parts of the basin, and the surficial cover of weathered material.

Alluvial deposits fill the stream channels of the drainage basin to various depths. The exact depth of alluvium in the main channel is unknown, although it is probably about 100 feet deep in the upper canyon and 50 feet deep in the lower canyon. The upper canyon fill seems to include a large amount of fine material and the lower canyon fill is largely coarse, angular pieces of quartzite.

This contrast in size of fill material is a result of differences in material available and gradients of the side slopes in the upper and lower canyon. There is more fine material available as weathered surficial deposits in the upper canyon because there is greater moisture available and more vegetation than in the lower canyon. The steeper side slopes in the lower canyon enable coarse material to move directly into the main channel by mass wastage processes.

Exposures of bedrock at various locations in the tributary canyons indicate that their depth of alluvial fill rarely exceeds 10 feet.

Colluvial deposits are present over the drainage basin as talus and landslide deposits. The outcrops of jointed and fractured quartzite weather to various sized fragments to produce material for the talus deposits. A few small landslide deposits occur in the tributary canyons on the south side of the main canyon in the upper part of the drainage basin.

Glacial deposits are present in the upper parts of the tributary canyons on the south side of Middle Canyon. They are best developed in the White Pine Flat "basin", which has the rough outline of a cirque. A lateral moraine about 30 feet high was observed on the eastern side of White Pine Flat, and the glacial and associated colluvial debris is at least 200 feet thick in the lower part of the flat. Gilluly (p. 40) stated that very small glaciers probably occupied the upper reaches of the highest northward-facing drainages in the Oquirrh Mountains during Wisconsin time.

The thickness of weathered surficial material varies over the drainage basin, chiefly as a result of processes that depend on the amounts of solar radiation received locally. Precipitation is fairly uniform over the basin at a given altitude, although north- and west-facing slopes may receive slightly more precipitation because they usually face passing storms. Precipitation is concentrated in the winter months and rising temperatures in the spring initiate snow melting. South-facing slopes receive the most solar radiation and their runoff is rapid. Because the north-facing slopes are protected from the direct rays of the sun and melting of the snow takes place more slowly, surficial material on these slopes is saturated for a longer period of time. This results in intensification of the weathering process and the production of greater amounts of weathered material on the north-facing slopes. This in turn produces more storage for moisture and further intensification of the weathering process. The increased amount of water in storage on the north-facing slopes results in more vegetative cover, which in turn furnishes some protection to the snow cover and further delays runoff. In addition, vegetation increases the weathering process, which adds to the soil cover and increases the water-storage potential.

Structure

Folds

The Oquirrh Mountains is an uplifted block of Paleozoic rocks that has been deformed into a series of broad folds that trend northwest-southeast. Gilluly (p. 69) stated that the axis of a transverse uplift crosses the range almost at right angles to the trend of the folds, and from this axis the folds plunge both north and south. The major folds are of large dimensions, as the southern half of the range is composed of only four of these folds. They are asymmetrical open folds, locally overturned. Minor folds or local warpings, called "small rolls" by Keith (p. 56), occur on the limbs of the major folds and have dimensions of a few hundred feet.

In the Oquirrh Mountains, the age of the folding can only be dated as post-Pennsylvanian and pre-Pleistocene. Geologic studies of nearby regions indicate a late Cretaceous to early Eocene, or Laramide, age for the folding in northern Utah (Gilluly, p. 73).

In Middle Canyon, the axis of the Long Ridge anticline lies across the southern part of the drainage basin in a northwest-southeast direction, roughly parallel to the main canyon. The axis of the Bingham syncline lies to the north of the Middle Canyon drainage and is parallel to the axis of the Long Ridge anticline. Both of these structures plunge to the northwest.

The northeast half of the upper canyon is a broad structural terrace, between and plunging with the more steeply-dipping limbs of the Long Ridge anticline and Bingham syncline. This structural terrace can be seen on structure section C-C' (fig. 3).

The folds tighten as they plunge to the northwest, as shown by a comparison of structure sections C-C' and A-A' (fig. 3). At the canyon mouth, the fold between the steeply-dipping northeast limb of the Long Ridge anticline and the structural terrace of the upper canyon has been compressed, and the terrace has been arched into a subsidiary anticlinal structure between the Long Ridge anticline and the Bingham syncline.

Faults

Gilluly (p. 74-90) classified the faults in the southern Oquirrh Mountains into four principal groups on the basis of location and relative age. Three of the fault groups are within the range, and are probably early Tertiary faults that occurred after the time of major folding. The fourth group includes the late Tertiary to Recent Basin and Range faults along the western front of, and possibly within, the range.

In a more recent report on the southern Oquirrh Mountains, Rigby (in Utah Geol. Soc., 1959, p. 229) stated that the folds, faults, and intrusions conform to a structural pattern. He reported that many of the folds are broken by strike-slip faults and cited as an example the fault that passes through the Fivemile Pass area on the southern edge of the Oquirrh Mountains, 18 miles south of Middle Canyon.

Keith (pp. 57-61) described faulting in the Bingham district and noted the large range in magnitude of the faults. This is probably a result of the brittleness of the quartzite, as major faults would cause fracturing and minor faulting in the surrounding rock. Keith also reported that the major faults are characterized by breccia zones from a few inches to several yards in width. These breccia zones are composed of small angular pieces of quartzite with a yellowish matrix of finely ground material.

Hunt (1933, p. 52-53) classified the faults in the Bingham district into four groups on the basis of attitude and relative age. The oldest faults strike northwest and dip gently to the west. They antedate the monzonite intrusions and all other faults, and may be older than the folding in the range.

The next group of faults is classified as bedding fissures. These faults are usually older than the intrusions and mineralization in the Bingham district. Gilluly (p. 88) discussed bedding faults in the Stockton area, five miles south of Tooele, and considered them to be contemporaneous with the folding in the area.

The third, and probably largest, group of faults includes high-angle normal faults that strike northeast and usually have displacements of less than 200 feet. These faults are thought to be equivalent in age to the late stages of intrusive activity, but antedate mineralization.

The youngest faults strike northwest and dip to the west. They are post-intrusion and post-mineralization in age and may be related to the Basin and Range faults along the western side of the range.

In Middle Canyon, the greatest concentration of faulting is in the upper canyon, and especially on the ridge separating the main canyon from Left Hand Fork. This faulting appears to be associated with the zone of monzonite intrusions that cuts across Middle Canyon in a northeast-southwest direction, as the strike of the faults parallels the trend of the intrusions. These faults are high-angle normal faults with displacements of about 100 feet, and probably correlate with Hunt's group of northeast-striking faults.

In the lower part of the canyon, there are fewer faults, and although a northeast strike is most common, north- and northwest-striking faults are present.

Many faults may have been overlooked in mapping the Middle Canyon drainage because the uniform lithology of the quartzites makes faults difficult to recognize. Only where a fault cuts a limestone bed can it be mapped with certainty.

The mountain-front scarp, at the mouth of Middle Canyon, is at or just southeast of a late Tertiary Basin and Range normal fault in which the mountain side is the relatively upthrown block. The 200 foot-wide zone of brecciated quartzite at the canyon mouth indicates a fault of large displacement, relative to the faults in the interior of the range. Quartzite beds up to a mile up canyon from the mountain-front fault are intensely jointed. This fracturing is probably related to movement along the fault.

There are probably additional faults northeast of, and parallel to, the fault at the mountain front. Gilluly (p. 84) stated that one characteristic of the Basin and Range faults along the west front of the Oquirrhs is their occurrence in *en echelon* zones with step-like displacements. This could explain the differences in elevation of the bedrock surface at various locations in the stream channel northwest of the canyon mouth. Bedrock was reached at less than 100 feet in the drilling of the city wells near the canyon mouth, but a well drilled more than 300 feet deep less than a half-mile downstream from the city wells didn't reach bedrock.

Joints

Jointing is common in the Oquirrh formation, although definite joint systems were not apparent in the Middle Canyon area. Joints intersect the beds at all angles; but the most common combination is a plane of jointing parallel to the plane of bedding and two or more joint sets normal to the bedding.

Keith (p. 61) stated that the joints in the Bingham district were developed regardless of folds and faults and at a later period. An investigation, in the spring of 1960, of the Utah Metals tunnel, whose Middle Canyon portal is in section 9, T. 4 S., R. 3 W., indicated that fractures and joints are often parallel to cross-bedding.

Jointing has a marked effect on the weathering of the Oquirrh formation, particularly the quartzites. The numerous joints facilitate the breaking off of the angular fragments of quartzite that form the talus slopes in Middle Canyon.

Geomorphology

The drainage of Middle Canyon is controlled by structure. The main channel roughly coincides with the sharp decrease in angle of dip where the steeply-dipping northeast limb of the Long Ridge anticline passes into the structural terrace between the Long Ridge anticline and the Bingham syncline. The main stream followed this fold in cutting its channel.

Possibly faulting also occurred along this sharp decrease in angle of dip, and broken, easily eroded rock along the fault influenced the stream course. Such a fault cuts the lower (Jordan) limestone in the west-center of section 6, T. 4 S., R. 3 W., and Roberts (oral communication, 1959) suggested that this fault may continue northwestward to the mouth of the main canyon. However, there is no definite evidence for faulting parallel to the channel along most of its length.

The uniform lithology of the Oquirrh formation in the Middle Canyon drainage basin indicates that erosion along weak strata probably didn't control the course of the main canyon.

The longitudinal profile of Middle Canyon, (fig. 4), along with profiles across the channel, (fig. 5), indicates that rejuvenation of the canyon has occurred. The longitudinal profile shows several nickpoints, the most prominent of which occurs at the boundary between the upper and lower parts of the canyon. The cross-profiles show that the upper canyon has a wider valley, a broader channel, and more gentle side slopes than the lower canyon. Because the upper canyon should be narrower with steeper side slopes than the lower canyon, a reversal of normal conditions has occurred. This reversal, and the sharp nickpoint at the place where the reversal occurs, suggests that uplift of the range along the mountain-front fault in the west has produced rejuvenation in the lower canyon. The hypothetical profile before rejuvenation is shown on figure 4.

Gilluly (p. 91) stated that uplift on the western edge of the range resulting from normal faulting began in the late Miocene or Pliocene and has continued to the present day. Erosion following these uplifts has destroyed the previous mature erosion surface and produced the present rugged topography. The differences in gradient and steepness between the upper and lower canyon are the result of the most recent of these uplifts.

The steeper side slopes in the lower canyon resulting from continued rejuvenation have aided in producing the contrast in texture between the coarse alluvial deposits in the lower canyon and the finer deposits in the upper canyon.

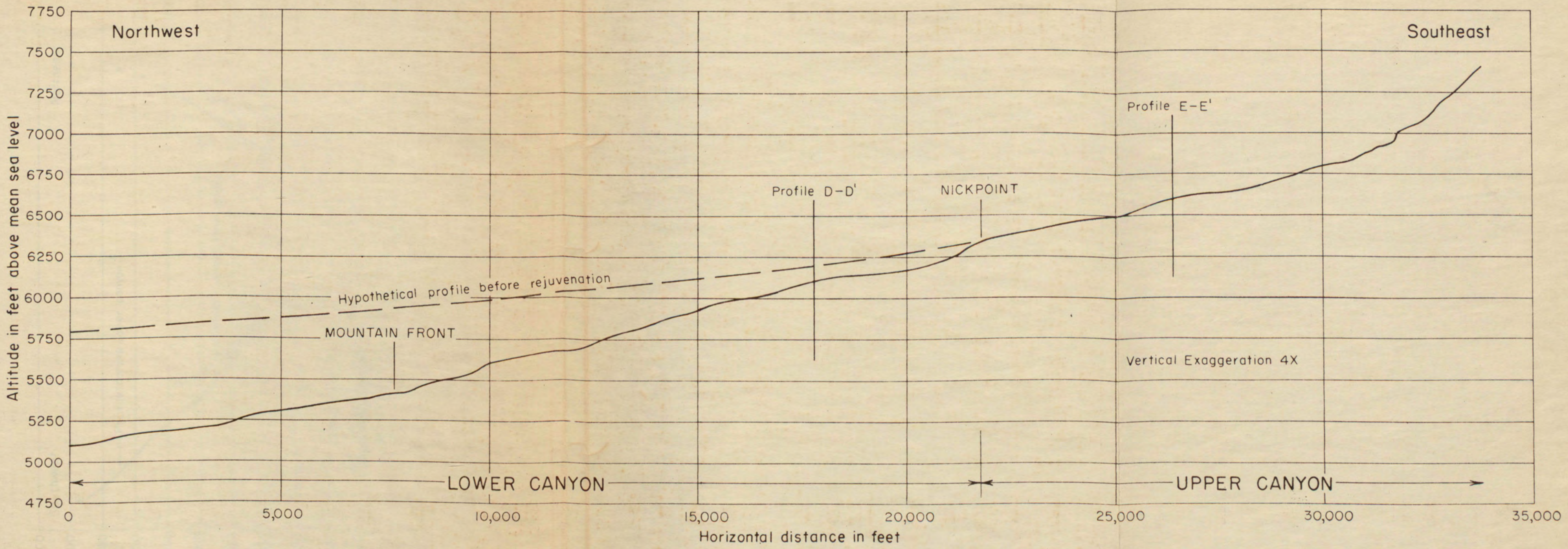

Figure 4.-- Longitudinal profile of Middle Canyon showing locations of the profiles across the canyon, the nickpoint, and the hypothetical profile before rejuvenation.

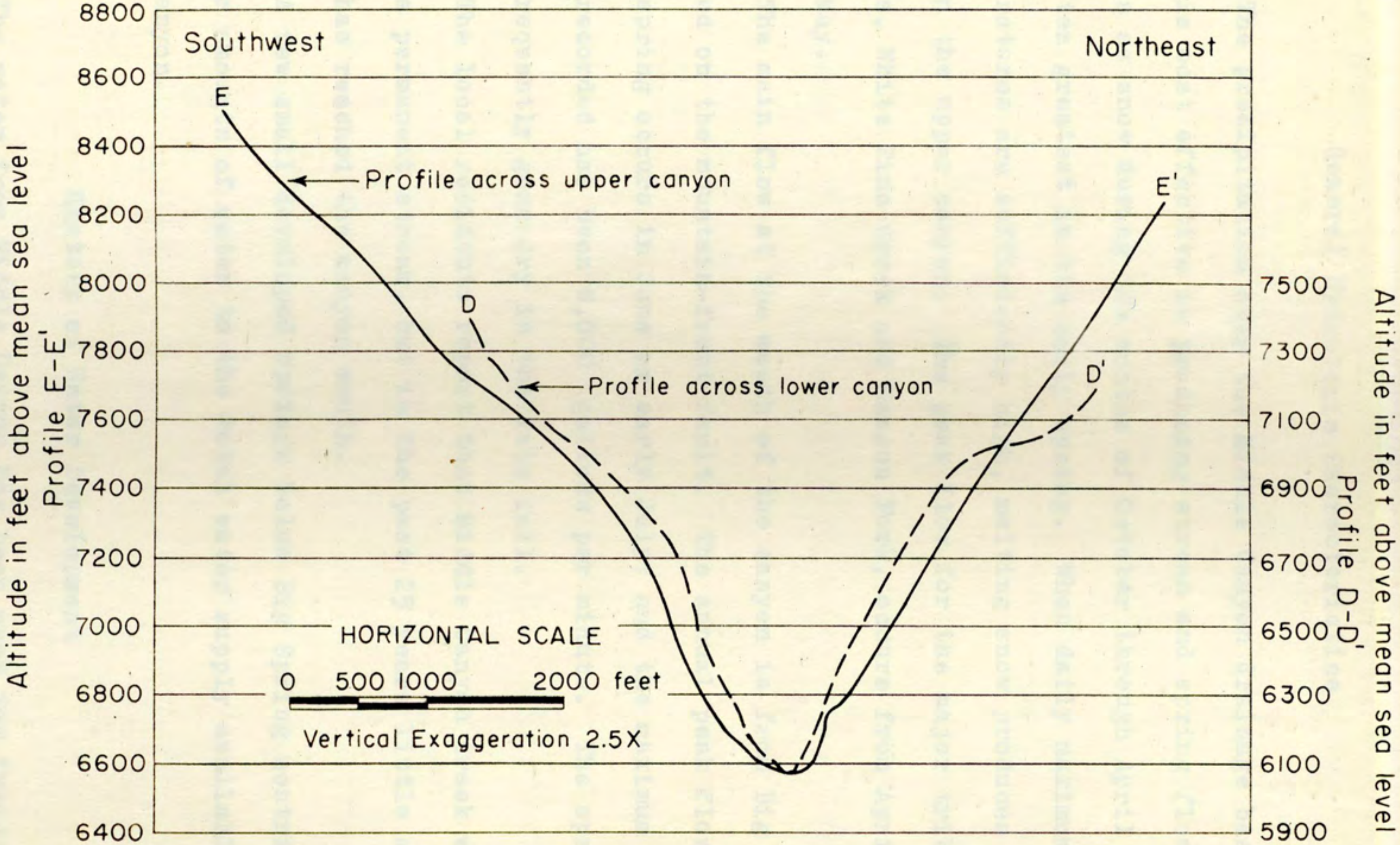

Figure 5.--Profiles across lower and upper Middle Canyon.

HYDROLOGY

General Hydrologic Characteristics

The precipitation over the Middle Canyon drainage basin that is most effective in producing stream and spring flow occurs as snow during the months of October through April and is often greatest in the early spring. When daily maximum temperatures are sufficiently high, melting snow produces runoff in the upper canyon. The peak flow for the major tributaries, White Pine Creek and Hanson Fork, occurs from April to late May.

The main flow at the mouth of the canyon is from Big Spring, located on the mountain-front fault. The annual peak flow of this spring occurs in June or early July; and the maximum peak flow recorded has been 8,000 gallons per minute. The spring has frequently gone dry in the late fall.

The local residents report that Middle Canyon Creek was once a permanent stream, but in the past 25 years little surface flow has reached the canyon mouth.

A few small developed springs below Big Spring contribute lesser amounts of water to the total water supply available from the canyon.

History of Water Development

The water from Middle Canyon has been used for irrigation east of Tooele since the area was settled in 1849. In 1906, the

Middle Canyon Irrigation Company was incorporated to organize distribution of the water and to make improvements in the irrigation system. Since the development work done during the drought of the 1930's, no major improvements have been made in the irrigation system.

The city of Tooele has long used for culinary purposes water from underground drains and springs developed at the canyon mouth by Thomas DeLaMare in the early 1900's. The small community of Lincoln, two miles northeast of Tooele, obtains its culinary water supply from a developed spring in the same locality. In addition, Tooele has the right to 190 gallons per minute from Big Spring; and has drilled several wells below the spring area, three of which are presently in use.

A few of the local mining companies have also had an interest in Middle Canyon water. In 1910, the Utah Metal Mining Company, which has since been absorbed by the Anaconda Company, sued the Middle Canyon Irrigation Company to obtain the right to use some of the upper canyon water for power generation during the driving of the tunnel from upper Middle Canyon to Carr Fork of Bingham Canyon. The Third District Court in Tooele granted Utah Metals the right to use the water provided they returned the water to the Middle Canyon drainage after using it.

In 1914, the Third District Court decreed the division of Middle Canyon water among those holding water rights in the canyon, and stated that the Utah Metal Mining Company owned the water developed by their tunnel. The Kennecott Copper Corporation later bought the rights to the tunnel water from Utah Metals and traded these water rights to the Middle Canyon Irrigation Company for the right to take an equivalent amount of water from the White Pine and Hanson drainages of upper Middle Canyon and pipe it through the tunnel to Bingham Canyon. Kennecott has since made weekly water measurements that show that the amount of water contributed by the tunnel has generally exceeded the amount taken from the upper canyon.

The city of Tooele and the Middle Canyon Irrigation Company, at the present time the major holders of water rights in the canyon, have long been in disagreement over development of Middle Canyon water. For almost 30 years, the irrigation company has advocated the construction of a pipeline to transport the water flowing in the upper canyon to the canyon mouth. They claim that a pipeline would prevent water from entering bedding planes in the bedrock and migrating out of the drainage basin. Tooele has opposed the construction of a pipeline, claiming that it would cut off the supply of water to their springs and drains at the canyon mouth.

In the drought years of the 1930's, the irrigation company, with Works Progress Administration aid, constructed short pipelines and rock- and concrete-lined ditches in parts of the upper canyon to reduce seepage losses.

In 1946, the irrigation company applied to the Soil Conservation Service for assistance in determining the best method of developing Middle Canyon water. The results of the 1947 water-measurement study by Lawrence and England (written communication, 1948) did not clearly indicate any water losses, but a few years later the Soil Conservation Service recommended the pipeline project. In 1953, the irrigation company applied to the Utah Water and Power Board for a loan to construct the pipeline.

The city of Tooele filed a protest against the pipeline with the State Engineer on the basis that it would reduce the flow of their springs and drains. On the advice of consulting geologists, the city rejected the theory that there were water losses in the upper canyon and claimed that essentially all of the upper canyon water percolates through the alluvial fill in the main channel to the mouth of the canyon.

As this protest has halted the pipeline project, subsequent efforts have been directed toward finding some compromise solution agreeable to the city and the irrigation company. Because the difference of opinion was about the amount of upper canyon water reaching the mouth of the canyon, a test drilling project was proposed by Tooele City in 1954 to determine the amount of water moving through the alluvium in the lower canyon. A drilling site was located below Left Hand Fork, where the lower (Jordan) limestone crops out across the main canyon. Because the city and the irrigation company have not been able to agree on the division of any unappropriated water discovered by test drilling, the project has not been begun. No progress has been made in the past few years toward a compromise solution.

Decrease in Discharge Since 1910

Local residents claim that Middle Canyon Creek was formerly a perennial stream, and that the total discharge from the canyon has decreased since the early 1900's. Records of the combined surface runoff and Big Spring discharge for 1906, 1909, and 1910 were obtained from the Tooele City files and hydrographs for these years were plotted. These hydrographs, along with hydrographs for 1939, 1940, 1941, 1942, 1947, 1953, 1954, and 1955 were used to calculate the total amount of discharge per water year in acre-feet. The discharge totals were plotted against the October through April precipitation of the corresponding and preceding years in an attempt to obtain a relationship between amount of flow and amount of precipitation (fig. 6). In support of the claims of local residents, the years in the early 1900's show a greater discharge for a given amount of precipitation than do more recent years.

Possible reasons for this decrease include man's activities or natural causes. There have been no activities of man such as lumbering, agriculture, or other development in Middle Canyon that could account for the decrease in discharge in the past 50 years. Many of the local residents believe that mining

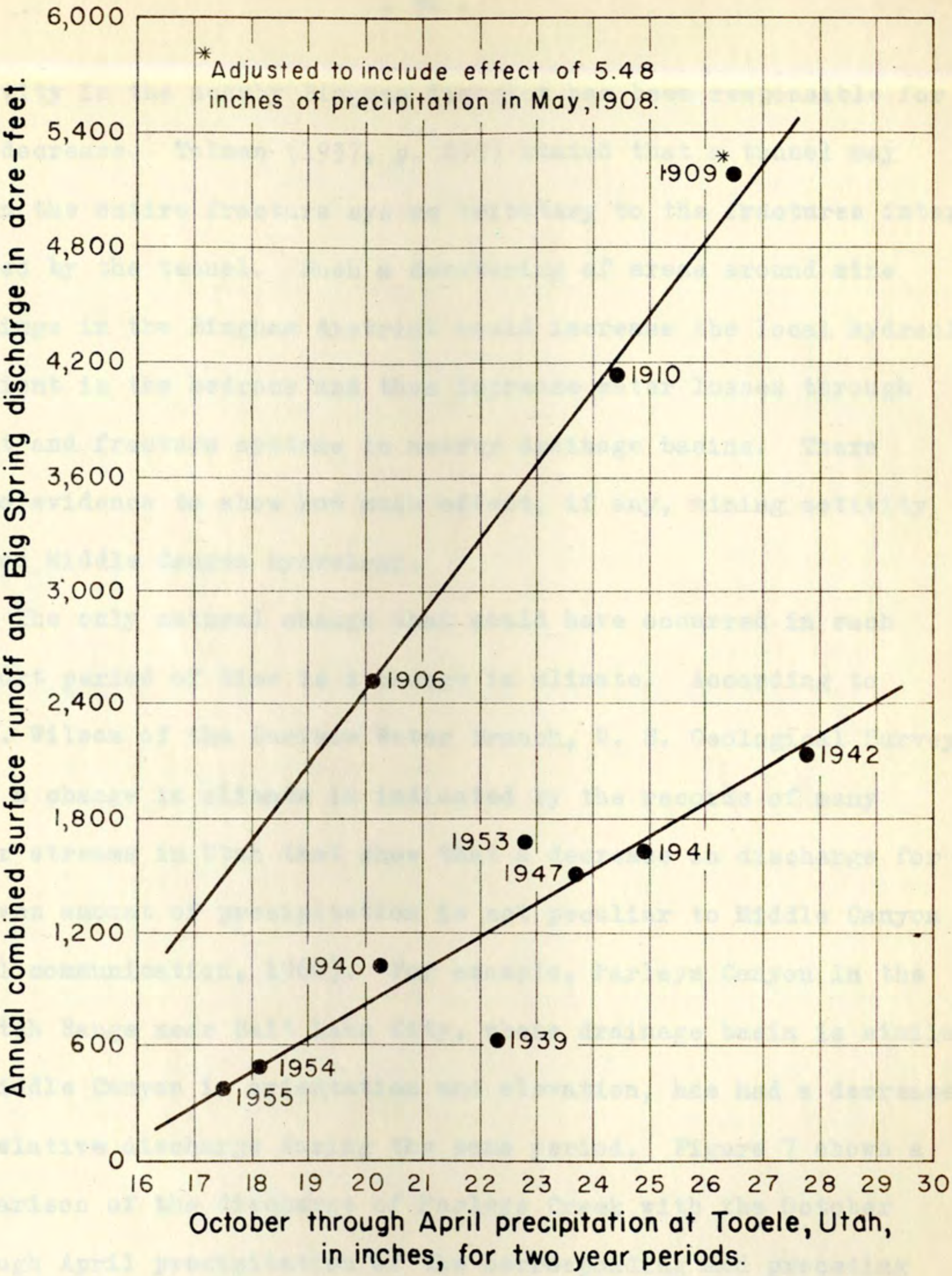

Figure 6.-- Comparison of discharge from Middle Canyon during certain years with the October through April precipitation at Tooele, Utah, for two years, the year of indicated discharge plus the preceding year.

activity in the nearby Bingham district has been responsible for the decrease. Tolman (1937, p. 299) stated that a tunnel may drain the entire fracture system tributary to the fractures intercepted by the tunnel. Such a dewatering of areas around mine workings in the Bingham district could increase the local hydraulic gradient in the bedrock and thus increase water losses through fault and fracture systems in nearby drainage basins. There is no evidence to show how much effect, if any, mining activity has on Middle Canyon hydrology.

The only natural change that could have occurred in such a short period of time is a change in climate. According to M. T. Wilson of the Surface Water Branch, U. S. Geological Survey, such a change in climate is indicated by the records of many other streams in Utah that show that a decrease in discharge for a given amount of precipitation is not peculiar to Middle Canyon (oral communication, 1960). For example, Parleys Canyon in the Wasatch Range near Salt Lake City, whose drainage basin is similar to Middle Canyon in orientation and elevation, has had a decrease in relative discharge during the same period. Figure 7 shows a comparison of the discharge of Parleys Creek with the October through April precipitation of the corresponding and preceding years at Salt Lake City. Because the same years were used for both figures 6 and 7, the two figures can be compared directly. It is apparent that since the early 1900's the same type of decrease in discharge has occurred in both Parleys and Middle Canyons.

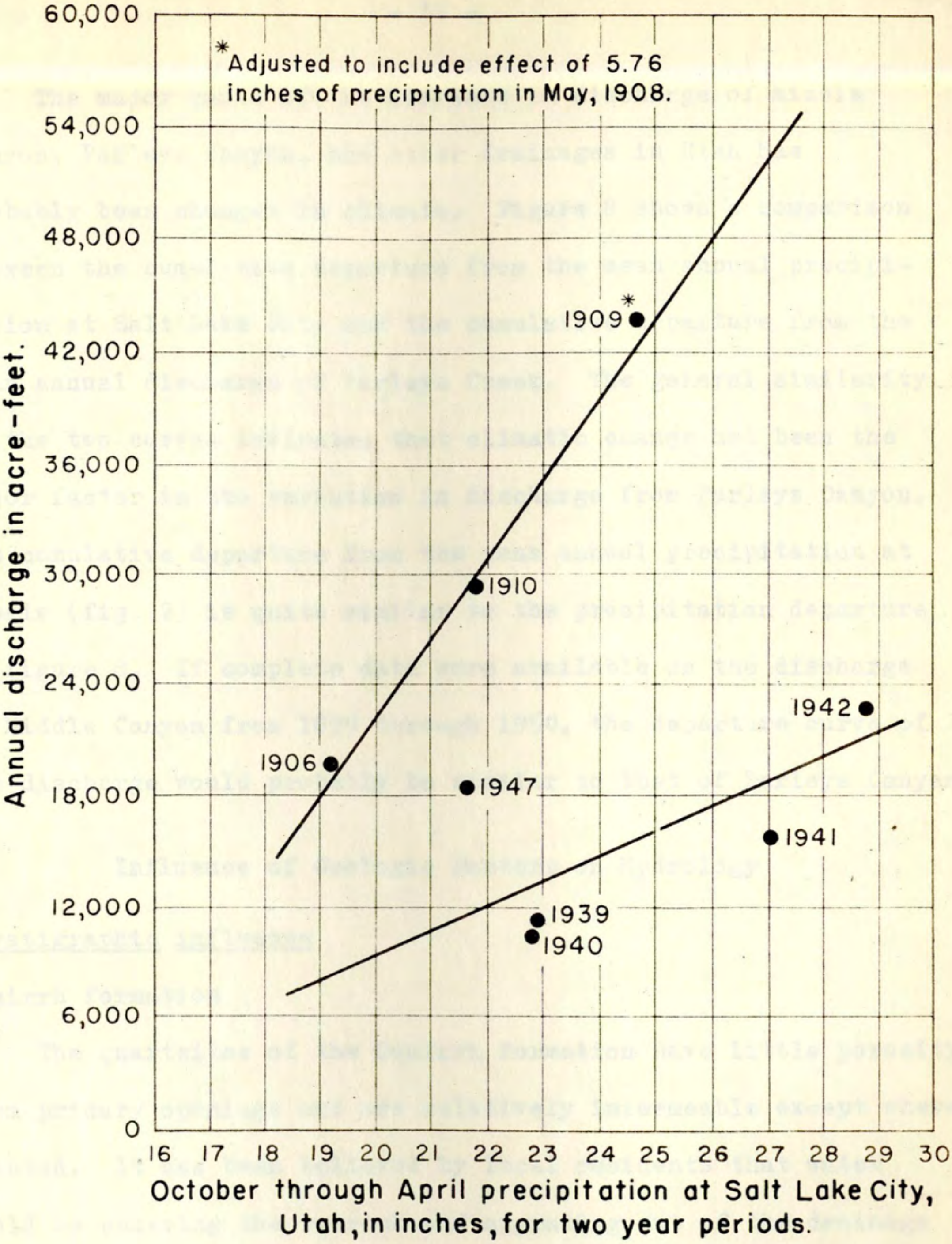

Figure 7.-- Comparison of discharge from Parleys Canyon during certain years with the October through April precipitation at Salt Lake City, Utah, for two years, the year of indicated discharge plus the preceding year.

The major cause of the decrease in discharge of Middle Canyon, Parleys Canyon, and other drainages in Utah has probably been changes in climate. Figure 8 shows a comparison between the cumulative departure from the mean annual precipitation at Salt Lake City and the cumulative departure from the mean annual discharge of Parleys Creek. The general similarity of the two curves indicates that climatic change has been the major factor in the variation in discharge from Parleys Canyon. The cumulative departure from the mean annual precipitation at Tooele (fig. 2) is quite similar to the precipitation departure of figure 8. If complete data were available on the discharge of Middle Canyon from 1899 through 1950, the departure curve of the discharge would probably be similar to that of Parleys Canyon.

Influence of Geologic Factors on Hydrology

Stratigraphic influence

Oquirrh formation

The quartzites of the Oquirrh formation have little porosity from primary openings and are relatively impermeable except where jointed. It has been believed by local residents that water could be entering the bedrock and migrating out of the drainage basin along bedding planes. This could occur if the bedding planes coincide with joint planes which are capable of transmitting water out of the Middle Canyon area.

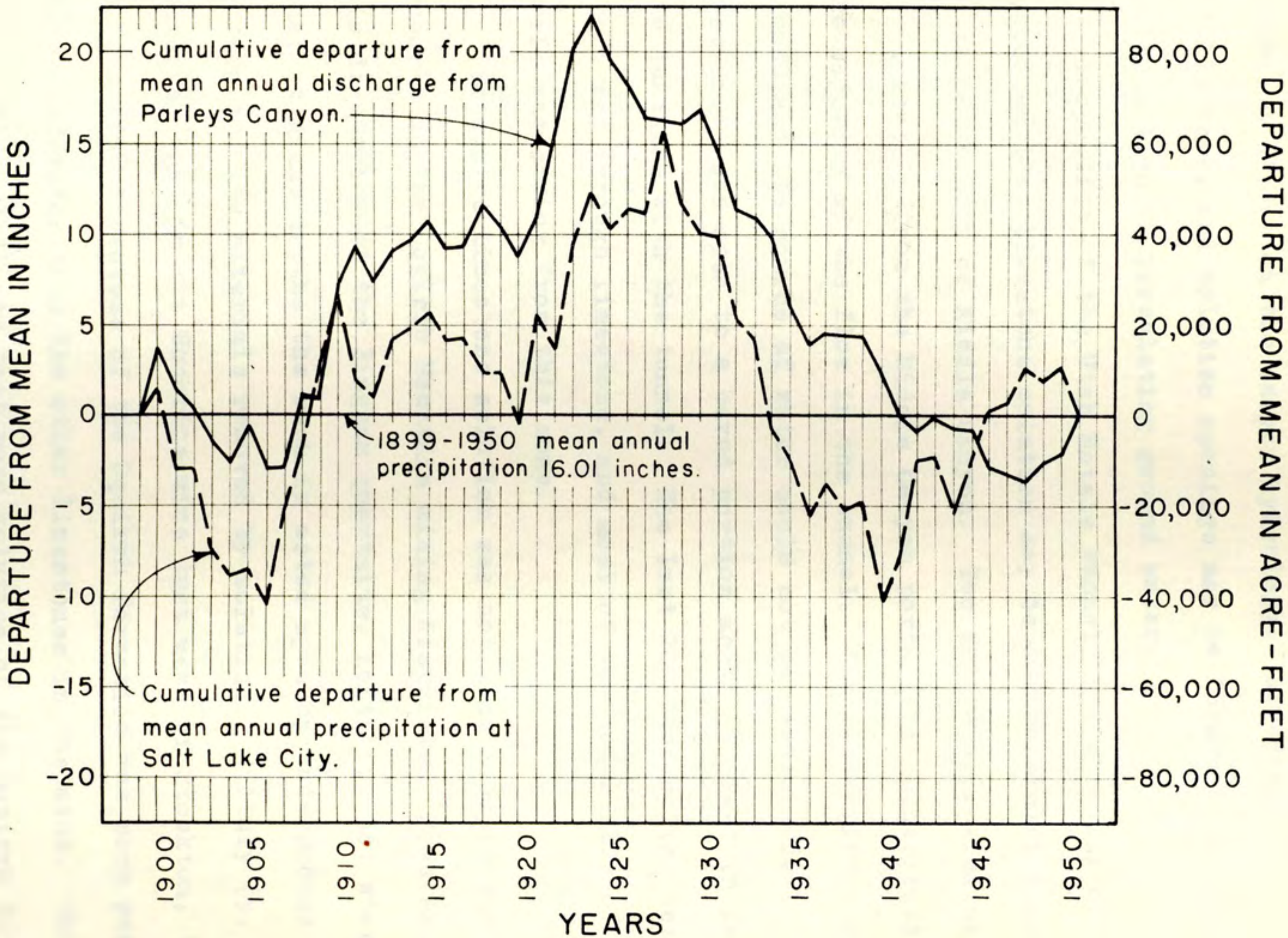

Figure 8.-- Comparison of cumulative departure from 1899-1950 mean annual precipitation at Salt Lake City, Utah, with cumulative departure from 1899-1950 mean annual discharge from Parleys Canyon.

The limestones of the Oquirrh formation could have an important effect on the canyon hydrology. Limestone is a soluble rock, and solution openings may be formed in limestone by the action of percolating ground water.

Inspection of the Utah Metals tunnel in the spring of 1960 indicated that limestone solution may be a significant factor in the hydrology of Middle Canyon. Two drifts approximately 7,400 feet in from the Middle Canyon portal were contributing the majority of the flow in the tunnel. The east drift was dammed and its source of water could not be determined; but the west drift was open to a caved portion about 600 feet in from the junction with the tunnel. The last 200 feet of the west drift was through limestone, and most of the total flow of the drift was coming from this zone.

Extensive limestone solution was not mentioned in any of the reports on the Oquirrh Mountain mining districts. However, in his discussion of the Bingham quartzite, Keith (p. 36) stated that at great depths the rock is acted upon by underground waters and its materials removed by solution. Gilluly (p. 162) observed that in the Honerine mine just west of Stockton, the Galena King limestone of the Oquirrh formation was more permeable to ground water than the other limestones in the mine. These observations indicate that some solution of the Oquirrh formation limestones occurs.

Limestone solution would most affect the hydrology of Middle Canyon at the outcrop of the lower (Jordan) and upper (Commercial) limestones in the north center of section 6, T. 4 S., R. 3 W. At this location, the main canyon is cut through more than 500 feet of limestone that dips downstream at an angle of 25 to 30 degrees. There is no surface evidence for limestone solution at this location, but long continued percolation of underflow across the outcrops in the channel may have formed solution openings in the two limestone beds.

The faults that cut the two limestone members on the north side of the upper canyon could have provided permeable zones in the limestones along which solution openings may be localized. Water could be moving toward the Bingham syncline through these solution openings in the limestone beds.

Quaternary deposits

The Quaternary deposits of Middle Canyon serve as the main storage and transmission material for the ground water of the drainage basin. Glacial deposits and weathered surficial material, especially on the southern side of the upper canyon, absorb large quantities of water from spring snow melt and prevent rapid runoff. White Pine Flat, with its great thickness of glacial and weathered debris, makes White Pine Canyon the best source of water among the tributaries to the main canyon. In contrast, the lesser thickness of surficial material in the Left

Hand Fork drainage is a factor in the small amount of sustained flow that this tributary contributes to Middle Canyon.

The alluvial material in the main channel consists of gravel, sand, and silt and is permeable to ground-water movement. Spring runoff in the upper canyon percolates into the channel fill and is transmitted as underflow to the mouth of the canyon where it furnishes most of the discharge of the springs and drains.

Structural influence

The folding in the Oquirrh Mountains could affect the hydrology of the Middle Canyon drainage basin if water is moving downdip through the bedrock on the flanks of the folds along bedding-plane joints or through solution openings in limestone beds.

Faulting and associated fracturing may have an important effect on the hydrology of the canyon. Water could be moving downward into the bedrock through fault zones and out into the valley fill bordering the range through interconnected fault and fracture systems. In Middle Canyon, most of the water losses in fault and fracture systems probably occurs in the fault zones in the upper canyon.

Jointing is common in the Oquirrh formation and may have a significant effect on the hydrology of Middle Canyon. The numerous joint sets in the Oquirrh formation may form relatively interconnected systems through which water could migrate out of the drainage basin.

Joints often control and facilitate the formation of solution openings in limestone. The numerous planes of jointing in the limestones of the Oquirrh formation indicate that, other conditions being favorable, these beds would be susceptible to solution.

Geomorphic influence

The observation that the topography of the upper half of Middle Canyon is more mature than the lower half was discussed previously. The broader channel of the upper main canyon has a greater thickness of alluvial fill and a higher proportion of fine material in the fill than does the channel of the lower canyon. The surficial material is thicker and more extensive over the upper canyon drainage area, and glacial and colluvial debris on White Pine Flat adds to the total amount of unconsolidated deposits in the upper canyon.

The greater thickness of unconsolidated material in the upper canyon, along with the more unsorted nature of the deposits, tends to make the upper canyon a better storage area than the lower canyon. Because ground water is held longer and moves more slowly in the upper canyon than in the lower canyon, any structural or stratigraphic condition that would result in migration of water through bedrock and out of the drainage basin would have a much greater effect on Middle Canyon hydrology if located in the upper canyon.

Hydrologic Budget

A hydrologic budget is a statement that balances the water gains and losses in a drainage basin over a given period of time. The 1947 water year, from October 1, 1946, to September 30, 1947, was selected as the period over which a hydrologic budget was to be calculated for the Middle Canyon drainage basin because the 1947 study of Lawrence and England has been the only comprehensive water measurement project done in Middle Canyon.

The following hydrologic budget will be discussed in succeeding sections.

Hydrologic Budget of Middle Canyon for the 1947 Water Year

	Acre-Feet
Water gains	
Precipitation	18,500
Utah Metals tunnel water	(cancelled by water piped to Bingham Canyon)
Total	18,500
Drainage-basin storage	No gain or loss

Water losses

Evapotranspiration	12,400
Big Spring flow and runoff	1,400
Tooele and Lincoln springs, drains, and wells	1,100
Channel underflow	500
Water piped to Bingham Canyon	(cancelled by Utah Metals tunnel water)
Total accounted for	15,400
Presumed leakage	3,100
Total	18,500

Water gains

Precipitation

The source of the Middle Canyon water supply is precipitation over the drainage basin. The Weather Bureau considers the October through April precipitation as being most significent in the hydrologic budget of an area in northern Utah. Precipitation during the remainder of the year is largely lost by evapotranspiration.

There are few data on precipitation in the Oquirrh Mountains; but unpublished Weather Bureau data are available on average October through April precipitation for different altitude zones in the Wasatch Range, Utah. The Wasatch Range data were used to calculate the average total amount of water added annually to the Middle Canyon drainage basin, although the Wasatch Range probably receives more precipitation than the Oquirrh Mountains. There is no major difference in the amounts of precipitation over the two mountain ranges, as shown by the comparison of the estimated mean annual precipitation of 31.6 inches at the White Pine Canyon storage gage at 7,000 feet elevation in the Oquirrh Mountains with the annual average of 32 inches at the 7,000 foot level in the Wasatch Range.

The areas in the Middle Canyon drainage basin included between successive 1,000 foot contours were measured on the topographic base map by planimeter. By multiplying the average precipitation over 1,000 foot intervals by the area within the intervals, the average annual effective amount of water added to the Middle Canyon drainage basin from precipitation was calculated to be 16,200 acre feet (table 1).

The October 1, 1946 to April 30, 1947 precipitation at Tooele was 124% above normal. Because a station at a low elevation will receive a larger percentage increase in precipitation in a wet year than a station at higher elevation, the precipitation at Tooele was not used to adjust the 1947 water year precipitation in Middle Canyon. The 114% of normal precipitation for October 1946 through April 1947 as recorded at the Farmington Rice storage gage, a station 15 miles north of Salt Lake City at 6,800 feet elevation in the Wasatch Range, was used to adjust

Table 1.-- Mean annual water gain from precipitation in Middle Canyon.

Elevation	Area	Mean October through April precipitation*	Mean annual amount of water added
Less than 6000 ft	0.3 square miles or 190 acres	15.8 inches	250 acre-feet
6000 - 7000 ft	2.3 " " or 1470 "	19.8 "	2430 " "
7000 - 8000 ft	4.4 " " or 2820 "	25.6 "	6000 " "
8000 - 9000 ft	3.6 " " or 2300 "	31.7 "	6080 " "
Over 9000 ft	0.7 " " or 450 "	38.5 "	1440 " "
Total	11.3 square miles or 7230 acres		16,200 acre-feet

* Data supplied by Eugene L. Peck of the U. S. Weather Bureau

the Middle Canyon precipitation. The corrected total effective amount of water added to the drainage basin during the 1947 water year was calculated to be 18,500 acre-feet.

Utah Metals tunnel water

The Utah Metals tunnel discharges from 100 to 400 gallons per minute to the upper canyon channel. Records kept by the Kennecott Copper Corporation show that this gain in water is approximately balanced by the water piped from Middle Canyon through the tunnel to Bingham Canyon. If the tunnel contributes water that would normally percolate into the main channel, this water could not be considered as a gain additional to the water derived from precipitation over the drainage basin; but the direction of movement of water through the bedrock in this area is not known because the study of the geology has not shown whether the water in the vicinity of the tunnel moves through solution channels, bedding-plane joints or fault zones, and therefore it is assumed here that the gain of water from the tunnel in 1947 exactly balanced the loss of water piped to Bingham Canyon.

It is difficult to determine whether or not water developed by the Utah Metals tunnel would normally move into the Middle Canyon drainage. Water moving along solution channels or bedding-plane joints would normally move to the north out of the drainage basin, following the dip of the sedimentary strata. Water moving along fault zones or joints not parallel to bedding may be moving either to the north out of the basin or south into the main channel of Middle Canyon, depending on the local hydraulic gradient. It is not known which of these outlets is most important in the vicinity of the tunnel.

Drainage-basin storage

Drainage-basin storage can be a significant factor in the calculation of a hydrologic budget. In a wet year following several dry years, a considerable amount of the precipitation is used in making up the moisture deficit in the surficial material and to some extent in the bedrock, of a drainage basin.

Although the Middle Canyon drainage does not have an extensive and thick cover of surficial material, the precipitation of the previous year has an effect on the annual discharge of Big Spring. A curve obtained by plotting Big Spring flow against October through April precipitation of the corresponding year plus that of the preceding year (fig. 6), gives a better representation of the increase in flow that results from increase in precipitation than does the curve representing Big Spring flow versus only the corresponding year's October through April precipitation.

Because the three years previous to 1947 had above normal annual precipitation (1944 - 124%, 1945 - 127%, and 1946 - 112%), there probably was little soil moisture deficit in 1947. For this reason, it is estimated that drainage-basin storage had no effect on the 1947 water budget.

Water losses

Evapotranspiration

Evapotranspiration losses include transpiration by plants and evaporation from the ground or from a snow surface. The amount of water lost in a drainage basin by evapotranspiration is obviously a difficult thing to calculate. Methods have been devised to calculate, from climatological data, the amount of evapotranspiration over large areas of uniform topography; but the application of these methods to small drainages in the Basin and Range province is not believed to be practical.

Fortunately, a study has been made of evapotranspiration losses in Parrish Canyon, a drainage in the Wasatch Range east of Farmington, Utah, and 15 miles north of Salt Lake City (Croft and Monninger, 1953). Elevations in this drainage basin vary from 4,600 to 8,900 feet, and the Parrish Creek Research Center is located at an elevation of 8,400 feet.

From 1946 to 1949, records were kept in Parrish Canyon of precipitation, rainfall interception, storm runoff, and yearly soil moisture deficits. Evapotranspiration losses for areas with various types of vegetation were calculated in inches of precipitation, and the differences between the total precipitation and the evapotranspiration were assumed to be water available for runoff and channel underflow. From table 9 (Croft and Monninger, p. 571), evapotranspiration losses for the 1947 water year can be calculated. The greatest loss occurred in an area covered by aspen-herbaceous vegetation, and was 44% of the total precipitation of the water year. Croft and Monninger (p.573) stated that these data on water available for stream flow should apply satisfactorily to steep mountain watersheds between 7,000 and 10,000 feet elevation.

Precipitation in the Oquirrh Mountains is probably less than in the Wasatch Range, and the percent of precipitation that represents evapotranspiration increases as the total precipitation decreases. Therefore, there is probably a greater relative amount of evapotranspiration in Middle Canyon than in Parrish Canyon. In addition, the lesser mass of the Oquirrh Mountains as compared to the Wasatch Range would result in higher temperatures and greater evaporation losses in the Oquirrhs.

Two thirds, or 67%, was used as the percent of precipitation lost by evapotranspiration in Middle Canyon. This percentage should allow for any greater relative evapotranspiration in the Oquirrh Mountains and should help compensate for any underestimation of water losses or overestimation of water gains in the hydrologic budget.

Multiplying the total water gain of 18,500 acre-feet by 67% gives 12,400 acre-feet as the total amount of water lost by evapotranspiration in Middle Canyon during the 1947 water year.

This leaves 6,100 acre-feet available for stream flow and channel underflow.

Big Spring flow and runoff

The most obvious loss of water from the drainage basin is the Big Spring discharge at the mouth of the canyon. The flow of Big Spring, combined with any surface runoff that reaches the canyon mouth, is measured by a 12-inch Parshall flume owned by the Middle Canyon Irrigation Company.

During the 1947 water year, the total flow over the irrigation company flume was calculated from careful measurements by Lawrence and England (written communication, 1948). From May 1, 1947, when Big Spring started flowing, to October 15, the total flow was 1,400 acre-feet. Subtracting this amount from the 6,100 acre-feet available leaves 4,700 acre-feet.

Tooele and Lincoln springs, drains, and wells

Tooele obtains water from Middle Canyon from Big Spring, from developed springs and drains, and from wells near the canyon mouth; and Lincoln obtains water from a developed spring at the canyon mouth. The 190 gallons per minute that Tooele City can take from Big Spring is diverted to the city system above the 12-inch Parshall flume, and is not included in the Big Spring total flow.

In their report, Lawrence and England (written communication, 1948) stated that the May 1 to October 1, 1947 amount of Middle

Canyon water used by Tooele and Lincoln, respectively, was 277 and 37 acre-feet. Dale James, former Tooele City Manager, (oral communication, 1959) said that the figure for city water use was too low and suggested using city water records to obtain a better estimate. Records were available for 1953, a year in which the total Big Spring flow of 1,650 acre-feet was comparable to the 1947 water year flow of 1,400 acre-feet.

The total amount of water used by Tooele in 1953 was 978 acre-feet. Rounding off this figure to 1,000 acre-feet and adding an estimated 1947 water year use of 100 acre-feet for Lincoln gives a total of 1,100 acre-feet for the water use by the two communities. Subtracting 1,100 acre-feet from the remaining 4,700 leaves 3,600 acre-feet.

Channel underflow

There is certainly some water being lost to the valley fill by channel underflow out of Middle Canyon. The water tapped by the Tooele city wells at the canyon mouth is part of this underflow, and additional water must be escaping from the canyon in this way. The amount of water obtained by the city wells is included in the 1953 city water records used to adjust the 1947 city water use, but the amount of additional water lost by channel underflow is difficult to estimate.

The city wells cannot pump more than a few hundred gallons per minute, and pumps on two of the three wells will break suction if they are in continuous use. This indicates that the channel fill just northwest of the canyon mouth has low permeability. Thus the amount of additional water lost by channel underflow is probably not in excess of a few hundred acre-feet per year. Subtracting an estimated 500 acre-feet from the remaining 3,600 acre-feet leaves 3,100 acre-feet.

Water piped to Bingham Canyon

The water loss represented by the water piped to Bingham Canyon through the Utah Metals tunnel is assumed to be balanced by the contribution of the water developed by the tunnel.

Leakage

After subtracting estimated evapotranspiration losses from the total amount of water added to the Middle Canyon drainage in 1947, there remains 6,100 acre-feet available for stream flow and spring discharge. The subtraction of additional water losses leaves a balance of 3,100 acre-feet unaccounted for, or approximately half of the available water. This balance unaccounted for should represent leakage from the drainage basin.

Records furnished by Professor Ray E. Marsell show the 1948 surface runoff, in acre-feet per square mile, for several creeks in the Wasatch Range near Salt Lake City.

Surface runoff of selected streams in the
Wasatch Range in 1948 and
discharge of Middle Canyon in 1947

1948*		
City Creek	623	acre-feet/square mile
Parleys Creek	466	"
Mill Creek	543	"
Big Cottonwood Creek	1110	"
Little Cottonwood Creek	1665	"
Neff Canyon Creek	332	"
1947		
Middle Canyon	150	"

*1948 figures furnished by Professor Ray E. Marsell

City Creek Canyon and Mill Creek Canyon are the drainages most comparable to the Middle Canyon drainage in area, elevation, and types of rock in their basins. The runoff totals for City Creek and Mill Creek, 623 acre-feet per square mile and 543 acre-feet per square mile, respectively, are much greater than the 150 acre-feet per square mile that Middle Canyon discharged in 1947. The 1948 discharge of Middle Canyon was probably less than 150 acre-feet per square mile because at Tooele the 1948 October through April precipitation was less than that of 1947. The comparison of these runoff figures also indicates that there is a significant amount of leakage from Middle Canyon.

Solution channels.--The possible effect of limestone solution on Middle Canyon hydrology was previously discussed. Water could be moving as underflow down the main channel and entering solution openings in the lower (Jordan) and upper (Commercial) limestones at the place where these beds crop out across the main channel. The outlet for this leakage could be the mountain-front fault, which certainly truncates the limestone beds at depth. Water could be moving downdip through the limestone beds to the fault zone, and then migrating along the fault zone until it could escape into the valley fill.

Fault zones and joints.--Leakage may be taking place along fault and associated fracture zones in the upper canyon. Water could be entering fault and fracture systems and eventually moving into the unconsolidated deposits in the intermontane basins bordering the range. There is some evidence that leakage is taking place along fault and fracture systems in the Oquirrh Mountains. Keith (p. 30) reported that in the Bingham district, the quantity of underground water is great at any time of year and its disposal is a serious question in the deeper mines. Mark R. Gardner of the Utah Water and Power Board, formerly a mining engineer at Bingham, stated that mine workings frequently intersected fracture zones in the quartzites that yielded considerable amounts of water (oral communication, 1960). Most of these zones were eventually drained, indicating a dewatering of the area around the tunnel or drift.

Jointing, although a possible cause of leakage of water from Middle Canyon, is probably not of major importance. Joints in the walls of the Utah Metals tunnel were observed to be contributing minor amounts of water. In the mine workings of the Bingham district, joints are not a major source of water (Mark R. Gardner, personal communication, 1960). Some leakage could be taking place in the zone of intense jointing near the mouth of the canyon, but most of the leakage probably occurs before the water reaches this point.

The greatest effect of jointing is probably that water moves into fault zones largely through nearby joint systems close to land surface. A fault zone can thus obtain water from a much larger area than is represented by its surface exposure.

Conclusions

The 1947 hydrologic budget for Middle Canyon is at best a rough estimate. Available data permitted little more than guesses for many factors in the budget. However, there does seem to be a significant amount of leakage from the drainage basin.

There may not be enough data to definitely locate areas of leakage. Leakage could be occurring along the whole length of the canyon, and not in localities such as the zone of faulting in the upper canyon or the outcrop of the limestone beds across the main channel.

However, most of the water in the mine workings in the Bingham district occurs in fault and fracture zones. Thus, leakage from the Middle Canyon drainage basin is most likely to be occurring through similar zones in the upper canyon.

Quality of Water

Four water samples were taken at different locations in Middle Canyon and their analyses were compared with analyses of older samples (table 2). Excepting the Utah Metals tunnel water, all of the water samples have similar chemical characteristics. Typical Middle Canyon water is a hard, calcium bicarbonate water containing 250-350 parts per million dissolved solids. If softened, this water is excellent for domestic purposes.

The Utah Metals tunnel water is more highly mineralized than the other water samples. The high sulfate content results from leaching of oxidized sulfides associated with the intrusive bodies in the vicinity of the tunnel. The high calcium and magnesium content indicates that the water had dissolved calcium carbonate, which supports the previous observation that limestone beds in the west drift are contributing most of the water to the flow in the drift.

The analyses of samples from the city's wells and developed springs at the mouth of the canyon do not suggest that this water has any source other than the upper canyon. The

Table 2.-- Chemical analyses of water from Middle Canyon

Source	Date collected	Field number	pH	Temperature (°F)	Specific conductance at 25°C (micromhos)	Chemical analysis in parts per million (ppm)														Percent sodium	Sodium adsorption ratio	Analysis by:
						Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Na + K		Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids	Hardness as $CaCO_3$				
										Sodium (Na)	Potassium (K)							Calcium and magnesium	Non carbonate			
1.[a] Tooele City Supply	2/26/41	-	-	-	-	4	0	69	22	26		58	20	40	0	Trace	334	263	-	-	-	PH
2. Lincoln Spring	12/15/50	-	-	-	-	9.5	0	62	27	16		277	40	17	0.2	2.0	312	264	-	-	-	PH
3. Lincoln Spring	3/1/51	-	-	-	558	12	0.02	76	22	14	2.7	298	39	15	0.1	2.4	320	280	-	10	-	GS
4.[a] Tooele City Supply	9/19/52[b]	-	7.86	-	-	3.2	0.08	79.6	6.9	45.5		283	67.3	15.8	0.3	0.03	358	227	-	-	-	PH
5.[c] White Pine Fork	8/5/59	MC-1	8.0	52°	435	12	0	54	20	10		246	20	10	-	2.1	249	216	14	9	0.3	GS
6. Utah Metals Tunnel	8/5/59	MC-2	7.9	48°	1070	11	-	124	72	13		280	369	16	-	1.2	744	608	378	5	0.2	GS
7.[d] Tooele City Supply	8/7/59	MC-3	7.8	49°	566	9	-	67	26	9.2		290	33	16	-	1.9	305	276	38	7	0.2	GS
8.[c] Hanson Fork	8/11/59	MC-4	7.8	49°	427	7.6	-	51	21	9.0		250	13	9	-	3.1	237	214	9	8	0.3	GS

a. Big Spring & developed springs at canyon mouth.
b. Date of report of analysis.
c. At Kennecott diversion.
d. Developed springs and 3 wells at canyon mouth.

PH - Analysis by Utah State Dept. of Public Health.
GS - Analysis by U. S. Geological Survey.

city water is slightly more mineralized than the upper canyon (White Pine and Hanson Forks) water, which is a reflection of the greater distance it has traveled.

Apparently the addition of the tunnel water does not have much effect on the chemical quality of the water at the canyon mouth. This could mean that the tunnel water is being diluted by channel underflow that is several times as great as the 200-300 gallons per minute tunnel discharge. Because underflow is considered to be small, a better explanation might be that in times of low flow during the late summer and fall, most of the upper canyon and tunnel water is lost by leakage. At this time, water from the city's springs and wells would be largely derived from lower canyon tributaries. During the spring runoff, the excess of upper canyon water over leakage moves down the canyon and furnishes the Big Spring discharge. At this time of year, there is sufficient underflow to dilute the tunnel water so its chemical characteristics are not noted in the water at the canyon mouth.

FUTURE DEVELOPMENT

A detailed discussion of possible methods of future development of Middle Canyon water is not within the scope of this report; but a few brief comments on this subject may be useful.

Completion of the drilling project proposed in 1954 would add valuable information on the movement of water in the drainage basin. The site originally chosen for the test holes, just above the outcrop of the two limestone members across the channel, would be a satisfactory location. Additional test holes below the limestone outcrops would help determine if any leakage is taking place through solution openings. Test drilling just above Big Spring would aid in the estimation of leakage in the lower canyon.

If test drilling indicates the leakage of large amounts of water through solution openings in the limestone, a number of wells or a cut-off dam above the limestone outcrops might be the best method of future development of Middle Canyon water.

If test drilling indicates leakage in the upper canyon, probably through faults and fractures, the possibility of constructing a pipeline down the canyon would merit further consideration. Much of the spring runoff in the upper canyon seeps into the channel fill and is eventually discharged from Big Spring.

If the proposed pipeline were constructed to bring most of this runoff to the canyon mouth, the discharge of Big Spring and the city's developed springs would diminish. The pipeline would save any surface runoff that seeps into the channel to replenish ground water lost by leakage. If the pipeline were only used to bring the water discharged from the Utah Metals tunnel down the canyon, there would probably be little effect on the springs at the canyon mouth. In the late summer, most of the tunnel water is evidently lost by leakage after seeping into the channel fill in the upper canyon; and this water would be saved by piping it down the canyon.

Removal of the trees in the main channel and on the alluvial fans of tributary canyons would decrease evapotranspiration losses, but whether this would save significant amounts of water is debatable.

SUMMARY

A hydrologic study was made of Middle Canyon to determine the total amount of water added annually to the drainage basin and the amounts available as stream flow and underflow, and to determine if any leakage was taking place in the canyon. The estimation of the hydrologic budget for 1947 indicated that approximately 50% of the water that should have been available during that year was missing.

A comparison of available records of total annual combined Big Spring and surface flow was made which indicated that the total annual discharge for a given amount of precipitation has decreased over the past 50 years. This trend has been observed in many other drainages in Utah, and is probably largely related to climatic changes.

A reconnsissance study of the geology of the canyon was made to determine the effect of geologic factors on the canyon hydrology. This study indicated that there were definite locations where leakage was most likely to be occurring.

Water could be moving into solution openings in the lower (Jordan) and upper (Commercial) limestone members at the point where these limestones crop out across the main channel, and moving out of the drainage basin along the solution openings.

The zone of faulting that trends northeast across the upper canyon could provide permeable fracture systems which would function as outlets for leakage from the drainage basin.

A third possible location for leakage is the area of intensely jointed quartzites near the mouth of the canyon.

There is no conclusive evidence to show that any of these locations is the chief area of leakage from Middle Canyon. Most of the water encountered in the Bingham district mine workings occurs in fracture zones, and such zones in other parts of the range probably are areas of leakage. The zone of faulting in the upper canyon is thus the most likely location for leakage in Middle Canyon. Additional leakage may be taking place through solution openings in the limestone beds, but except for possible leakage through limestone, there is probably not much leakage in the lower canyon.

More information is needed on the amounts of underflow in various reaches of the canyon to definitely locate zones of leakage. The proposed test drilling project should be completed to provide much of this information and aid in the planning of future development for Middle Canyon water.

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